Positional Accuracy of Two Methods of Geocoding

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Background: Geocoding is often used in epidemiologic studies to map residences with geographic information systems (GIS). The accuracy of the method is usually not determined.

Methods: We collected global positioning system (GPS) measurements at homes in a case–control study of non-Hodgkin lymphoma in Iowa. We geocoded the addresses by 2 methods: (1) in-house, using ArcView 3.2 software and the U.S. Census Bureau TIGER 2000 street database; and (2) automated geocoding by a commercial firm. We calculated the distance between the geocoded and GPS location (positional error) overall and separately for homes within towns and outside (rural). We evaluated the error in classifying homes with respect to their proximity to crop fields.

Results: Overall, the majority of homes were geocoded with positional errors of less than 100 m by both methods (ArcView/TIGER 2000, median = 62 m [interquartile range = 39–103]; commercial firm, median = 61 m [interquartile range = 35–137]). For town residences, the percent geocoded with errors of ≤100 m was 81% for ArcView/TIGER 2000 and 84% for the commercial firm. For rural residences, a smaller percent of addresses were geocoded with this level of accuracy, especially by the commercial firm (ArcView/TIGER 2000, 56%; commercial firm, 28%). Geocoding errors affected our classification of homes according to their proximity to agricultural fields at 100 m, but not at greater distances (250–500 m).

Conclusions: Our results indicate greater positional errors for rural addresses compared with town addresses. Using a commercial firm did not improve accuracy compared with our in-house method. The effect of geocoding errors on exposure classification will depend on the spatial variation of the exposure being studied.

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Geographic information systems (GIS) are increasingly being used in epidemiologic studies of environmental exposures and health.[1,2] Proximity to sources of exposure such as roadways, hazardous waste sites, or crop fields is often used as a surrogate for environmental exposure.[3–7] Study participant addresses are typically geocoded, but the spatial accuracy of the location is not typically determined.

Geocoding, sometimes called address matching, is a method for estimating the location (coordinates) of an address by matching to a georeferenced street map that contains the spatial location of the street center (street centerline) and the range of addresses between street intersections (street segment).[8–10] With an exact match to the database, coordinates are assigned to an address by assuming an equal spacing of homes along a street segment. Geocoding errors may be large in rural areas because of large distances between homes and because homes may be far from the road. Two studies in New York State[11,12] found greater positional errors for addresses outside urban areas.

In the United States, the Topologically Integrated Geographic Encoding and Referencing (TIGER) street database developed by the U.S. Census Bureau is the basis of most geocoding software. Some commercial geocoding firms update and spatially correct TIGER, although the extent of error checking is not known by the user.

We determined the positional errors associated with geocoding addresses from a population-based case–control study of non-Hodgkin lymphoma in Iowa. We compared global positioning system (GPS) measurements at homes (gold standard) with locations obtained by (1) geocoding using a commercial vendor and (2) ArcView GIS software with the TIGER 2000 street database. We also determined the effect of the positional errors on exposure metrics that classify homes according to their proximity to crop fields.

METHODS

Study Population

The study design has been described in detail elsewhere.[13] The study population comprised 4 areas covered by the Surveillance, Epidemiology, and End Results program of the National Cancer Institute: the state of Iowa; the Detroit, Michigan metropolitan area; Los Angeles County, California; and the Seattle, Washington metropolitan area. Only Iowa participants were included in these analyses. We identified as eligible, cases newly diagnosed with non-Hodgkin lymphoma who were age 20–74 years at diagnosis. The diagnosis dates were between July 1998 and March 2000, and 361 (67%) of the eligible cases in Iowa were interviewed. We selected controls age 20–64 years from the general population of Iowa using random digit dialing and controls age 65–74 years from Medicare eligibility files. Controls were matched by age group, sex, and race to parallel the distribution in the cases. We selected 478 controls and interviewed 276 (58%) of them.

Global Positioning System Measurements

Interviewers requested permission to take a GPS measurement outside the home; all 637 study participants agreed. We used the Garmin GPS12 Personal Navigator, a 12-channel small handheld receiver (Garmin International, Inc., Olathe, KS). Interviewers took the measurements 6.1 m (20 ft) away from the home; measurements were not obtained for 3 participants.

Our analysis includes 234 residences from 43 counties in south central Iowa, an area for which we created crops maps from satellite imagery to estimate residential exposure to crop pesticides.[14] Because the GPS measurements were to be used as the gold standard in our analyses and because many readings (72%) were taken before the end of selective availability (deliberate corruption of GPS satellite signals resulting in errors of 100 m or more),[15,16] we checked the GPS coordinates for possible errors. First, we used a database from the Iowa Department of Transportation[17] to determine if the GPS coordinate was inside an incorporated area (hereafter called town) or outside (hereafter called rural). We looked up rural addresses in plat books (rural directories with maps showing the location of homes and property owners). Digital orthophotography (circa 1990) was used to locate the home. If necessary, the GPS measurement was corrected by assigning the coordinates of the identified home. For rural addresses that were not found in plat books, staff located the address by driving the area, identified the home on aerial photography, and corrected the coordinates if necessary.

For town residences, we compared the GPS coordinates with Census Bureau TIGER 1990 street files, Iowa Department of Transportation road maps, MapQuest (www.mapquest.com), and a database containing addresses and coordinates of underground storage tanks.[18] If the GPS coordinates did not correspond with the address locations in these databases, the home was identified on an aerial photograph and the coordinates were corrected. When the location was not clear from the photography and other data, the staff drove to the address, located the home on the aerial photo, and assigned the correct coordinates.

Geocoding

We sent the addresses to a commercial firm to be geocoded by batch matching using their proprietary software and street database. The company enhances the TIGER street files by doing spatial corrections and address updates. For addresses that were not geocoded on the first attempt, we checked for misspellings and for different iterations of the address using MapQuest. The corrected addresses were sent again for batch matching by the firm.

We also geocoded the corrected addresses using ArcView 3.2 software (ESRI, Inc., Redlands, CA) and the TIGER 2000 street map file. Addresses were geocoded to a spelling score of 80 and a minimum match score of 60. Addresses with a match score of 75 or more were considered a good match, whereas a score of 60–74 was considered a partial match. For both methods of geocoding, we used a 13-meter (40-foot) offset from the street centerline.

Data Analysis

We converted the GPS and geocoded coordinates to a common coordinate system and datum (Universal Transverse Mercator, Zone 15 N, NAD 1927). We computed the linear distance between the GPS coordinates recorded by the interviewers and the coordinates after our quality-control checking. We compared the distances before the removal of selective availability with the distances after its removal.

We determined the positional error of the geocoded coordinates by computing the spherical distance between the corrected GPS coordinates and both sets of geocoded coordinates using ArcGIS 8.3. So that we could easily compare our results with a study by Bonner,[11] we grouped the positional errors into categories (≤25 m, 25–50 m, 51–75 m, 76–100 m, 101–200 m, 201–400 m, 401–599 m, 600–800 m, >800 m) and computed the percentage of addresses with errors in each category. We compared the positional errors for rural and town residences and by the size of the communities in 2000.

We calculated the specificity and sensitivity of crop occurrence within 500 m, 250 m, and 100 m of residences based on the geocoded locations using the GPS as the "gold standard." We also determined the differences between the geocoded location and GPS for the percent of the area around homes (circular buffers) that was corn or soybean fields. Only residences for which the 500-m circular buffer lay completely within a 2000 crop map were included (n = 205).

RESULTS

Global Positioning System

We determined that 16% of the original 234 GPS coordinates were more than 100 m away from the true location of the residence. The proportion changed little before (17%) and after (15%) the removal of selective availability;

however, the distance between the original and corrected coordinates was greater before selective availability was removed (median = 30 m; interquartile range [IQR] = 0–78 m) compared with afterward (15 m; 0–50 m).

Geocoding

The exact match rate was higher for the commercial firm (92%) than for the combined good and partial matches by ArcView/TIGER 2000 (88%). Eighty-four percent of the addresses were matched by both methods.

Positional errors for ArcView/TIGER 2000 matches classified as partial (n = 8; range = 14–66 m) were lower or similar to errors for good matches (n = 197; median = 65; IQR = 40–108); therefore, we combined them in our analyses. Overall, the percent of residences geocoded with positional errors of 100 m or less was similar by both methods (ArcView/TIGER 2000, 74%; commercial firm,70%) (Table 1). For town residences, the percent with errors of 100 m or less was 82% for ArcView/TIGER 2000 and 85% for the commercial firm. For rural residences, the percentages were 56% and 28%, respectively. Positional errors of greater than 800 m occurred more frequently among rural addresses geocoded by the commercial firm (23%) compared with ArcView/TIGER 2000 (6%).

For town residences, we evaluated positional accuracy by population size (Table 2) and found only small differences in the median positional error by town size for both methods of geocoding. The greatest range in errors occurred for addresses in the smaller towns (<6884 population) that were geocoded by the commercial firm.

When we restricted the analyses in Tables 1 and 2 to the 197 residences that were successfully geocoded by both methods, the distribution of positional errors by each method changed very little (not shown). By both methods of geocoding, there were only minor differences in the overall positional error among cases and controls (not shown).

Geocoding Errors Effect on Classification of Residential Proximity to Crops

The prevalence of corn and soybeans within 100, 250, and 500 m of homes ranged from 16% (soybeans, 100 m) to 85% (corn, 500 m) (Table 3). The sensitivities and specificities were similar for both methods of geocoding. The greatest reductions in sensitivity and specificity occurred for the 100-m buffer distance.

For most residences, the percent of the buffer area that contained corn or soybean fields computed using the geocoded locations differed little for the 2 geocoding methods (supplementary table, available with the electronic version of this article). The only major difference for both methods was for the percent of the 100-m buffer that contained soybean fields. However, the range in errors (both under- and overestimation of percent of the buffer area in crops) was consistently larger for the commercial firm. For example, the range in errors for the percent of the 250-m buffer in soybeans was

TABLE 1. Positional Error (Meters) of Geocoded Coordinates Overall and for Town and Rural Residences for 2 Methods of Geocoding

	ArcView/TIGER 2000			Commercial Firm		
Positional Error (m)	All (n = 205)	Town* (n = 152)	Rural* (n = 53)	All (n = 215)	Town* (n = 159)	Rural* (n = 56)
Mean ± SD	111.7 ± 178.2	77.3 ± 80.6	210.3 ± 303.8	277.5 ± 949.9	84.8 ± 162.6	824.7 ± 1738.5
Median (IQR)	62 (39–103)	56 (36–92)	88 (45–254)	61 (35–137)	50 (28–83)	212 (89–747)
Range	2–1731	2–687	14–1731	0.4–11,064	0.4–1460	6–11,064
Distance (%)†						
≤25	12	12	13	16	21	4
26–50	25	30	13	24	28	14
51–75	21	22	21	18	22	5
76–100	16	18	9	12	14	5
101–200	14	14	15	13	11	16
201–400	6	4	13	7	2	20
401–600	2	1	6	1	0	5
601–800	1	1	4	3	1	7
>801	1	0	6	7	1	23

*Town residences were within Iowa incorporated areas database; other residences were defined as rural.
†Percentages may not sum to 100 because of rounding.

TABLE 2. Positional Error (Meters) of Geocoded Coordinates by Size of Town for 2 Methods of Geocoding

	Population Size		
	265–6658	**6,884–27,117**	**29,072–198,682**
ArcView/TIGER 2000			
No. of towns	43	53	56
Positional error			
Mean ± SD	72.1 ± 62.2	83.4 ± 96.5	75.6 ± 77.8
Median (IQR)	58 (32–84)	59 (37–94)	54 (33–96)
Range	2–291	5–687	7–531
Commercial firm			
No. of towns	47	53	59
Positional error			
Mean ± SD	130.0 ± 271.8	74.1 ± 97.5	56.37 ± 49.20
Median (IQR)	53 (34–90)	51 (35–83)	41 (25–77)
Range	9–1460	2–700	0.4–267

TABLE 3. The Effect of Errors From 2 Methods of Geocoding on the Sensitivity and Specificity of Classifying Residential Proximity to Crops*

		Sensitivity‡ (%)		Specificity§ (%)	
Distance From Residence (m)	**Prevalence† (%)**	**ArcView/ TIGER**	**Commercial Firm**	**ArcView/ TIGER**	**Commercial Firm**
Corn					
100	44	92	91	90	88
250	67	95	95	94	91
500	85	98	98	93	100
Soybeans					
100	16	79	79	93	92
250	40	94	90	94	96
500	68	94	94	94	95

*Analysis includes 205 homes for which the 500-m circular buffer lay completely within the boundaries of the crop map; crop map was created from 2 LandSat satellite images from south central Iowa in 2000.

†Percent of homes with >0 acres of the crop in the circular buffer based on the GPS location.

‡Percent of homes exposed (>0 crop acres within the buffer) that were correctly classified as exposed by the geocoded location.

§Percent of homes unexposed (0 crop acres within the buffer) that were correctly classified as unexposed by the geocoded location.

−64% to 74% for the commercial firm and −50% to 49% for ArcView/TIGER.

DISCUSSION

In our evaluation of 2 popular methods of geocoding addresses, we found exact match rates greater than 85%. The commercial firm returned a slightly higher percent of exact matches than our in-house method using ArcView/TIGER 2000. The commercial firm updates and corrects the street database, which is derived from TIGER, and this may explain the higher match rate. However, different matching rates may also be due to differences in the algorithm used to match an address to a street segment, specifically the strictness in the criteria used to return an "exact match." Some batch-matching programs search for eligible street segments within a zip code and then stop looking if there are no candidate street segments, whereas other programs go on to the city level to look for eligible street segments. The latter approach is more likely to result in a match when there are errors in zip codes for study addresses. The degree of flexibility allowed in misspellings also results in different matching rates for the same set of addresses.

By both geocoding methods, most town addresses were geocoded to within 100 m of their GPS location, regardless of the size of the town. In contrast, the positional error for rural addresses was substantially larger for both geocoding methods. Errors greater than 100 m occurred much more frequently for the commercial firm (56% of rural addresses) compared with ArcView/TIGER 2000 (28% of rural addresses), indicating that the improved street maps used by the commercial firm did not result in improved accuracy for rural addresses.

Possible reasons why geocoded rural addresses were less accurate than those in towns are related to the geocoding process. Addresses are geocoded to an exact location by interpolating to estimate the relative position of the home number along a street segment. Larger street segments would be expected to result in larger interpolation errors if the assignment of street numbers had not taken into account the distance between homes. In addition, many rural homes are located at fairly large distances from the road. We used a constant 13-m (40-ft) offset from the street centerline for all addresses, which is presumably more accurate for homes within towns and cities. The positional accuracy of the geocoding process is determined by 3 main factors. First, inaccuracies in the database or input street address information may lead to an incorrect match. Second, positional accuracy is affected by the spatial accuracy of the street database. Positional errors in TIGER street centerline locations were estimated to be 30–121 m.[19] The positional accuracy of the firm's street database was not known to us. Finally, the matching algorithm itself can result in an incorrect match of an address to the street database.

We expected lower positional errors for addresses geocoded by the commercial firm because of their ongoing spatial corrections and updates to their street database. However, our results indicate that geocoding to the TIGER 2000 street map gave similar accuracy for town addresses and improved accuracy for rural addresses. One partial explanation may be that the firm's updates for rural areas of Iowa may not have been extensive. Another reason for the larger errors for the commercial firm may be related to the matching algorithm used. Thus, in our study area, the use of a well-established commercial firm offered no clear advantages to in-house geocoding using ESRI ArcView software and the TIGER 2000 street database. Furthermore, in-house geocoding may offer some advantages with respect to the transparency of the geocoding process and possible cost savings.

Whether our results represent expected geocoding errors in other areas of the United States is not known. A study by Krieger et al[20] compared geocoding firms and found widely varying geocoding success rates, as well as large differences in the accuracy of census tract assignment. Our findings are largely consistent with Bonner and colleagues[11] who found positional errors of less than 100 m for 79% of addresses in 2 counties in western New York; however, errors for nonurban addresses (median = 52 m) were substantially lower than the errors we observed for rural addresses. Differences between our studies may be due to the fact that nonurban addresses in the Bonner study included mostly suburbs and small towns, as well as to the fact that the GPS measurements were taken at the street in front of the home, whereas we took them a short distance from the home. A recent study in 4 counties in northern New York[12] found that positional error increased with decreasing population density. Errors for rural addresses (median = 201 m) were larger than those we obtained using ArcView/TIGER 2000; however, they were similar to those we obtained using the commercial firm. Those investigators used MapMarker Plus (MapInfo, Troy, NY) software and street database enhanced by Geographic Data Technology (Lebanon, NH).

Geocoding of rural addresses can be problematic because some areas of the country still use rural routes, which cannot be geocoded. Rural routes and postal boxes can be assigned the coordinates of zip code centroids or excluded from analyses, but both approaches can result in misclassification of exposure and biases in disease rates.[21–23] Even when rural addresses can be geocoded, results of our study and others[11,12] indicate that positional errors are likely to be larger than for addresses in towns. Furthermore, as indicated by our study and that of Krieger,[20] the choice of a geocoding method affects both geocoding success and the positional error. Therefore, careful consideration should be given to the approach used for geocoding. Helpful guidelines for choosing a geocoding method using street databases have recently been discussed.[10,24]

Geocoding using property boundary maps, in which the coordinates of the center of the land parcel are assigned to the address,[12,25,26] has been suggested as a more accurate alternative to geocoding to street maps; this approach was shown to be more accurate than geocoding in the study in northern New York.[12] However, the proportion of residences geocoded to parcel maps may be lower than the proportion geocoded using digital street maps, and this method may be costly and time-consuming if digital parcel maps are not available.[26]

We mapped Iowa residences to evaluate potential exposure to agricultural pesticides through the proximity of homes to crop fields. The crop maps were created from georeferenced LandSat satellite imagery, which had an estimated spatial accuracy of 15–20 m, substantially better than that of the TIGER street map. We did not align the street map with the imagery-based map to spatially correct the geocoding reference layer, a procedure known as "rubber sheeting."

Rubber sheeting could have resulted in lower positional errors for the geocoded locations. We found that positional errors from geocoding errors did not cause large reductions in the sensitivity and specificity of the crop area metrics. Furthermore, geocoding errors did not translate into substantial differences in the percent of the area near homes that was crop fields except for distances of 100 m. The relatively small effects of geocoding errors on our exposure classification are most likely because the land cover was predominantly agricultural and the majority of homes were within 500 m of corn or soybean fields. Greater misclassification would be expected in areas with more diverse agriculture or where a smaller proportion of the population lives near crop fields. Because positional errors from geocoding can cause misclassification of exposure, there should be an *a priori* evaluation of the geospatial resolution needed at the design stage of an epidemiologic study.[2]

In summary, the collection of a GPS measurement in epidemiologic research is desirable due to the inherent problems with geocoding addresses. However, many studies will have to rely on geocoding for locating residences because it may not be feasible or affordable to collect GPS measurements. Furthermore, the estimation of past exposure requires information from residential histories, and obtaining GPS readings at past residences may be cost-prohibitive. Our results are consistent with 2 recent studies[11,12] in New York State, which indicate that the majority of addresses located in towns can be geocoded with errors of less than 100 m; however, larger errors occurred for rural addresses. There was no advantage to using a commercial firm for geocoding; positional accuracy for rural addresses was substantially lower compared with our in-house method. The choice of a geocoding method and the effect of positional errors on the exposure metrics used in a study should be carefully considered.

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